Hydrogen isotope ratios of volcanic glass: Making an isotopic map of Western North America to study paleoelevation in the late Paleogene period

Gabriella Rossetto
Advisor: Dr. Henry Fricke, Colorado College; Mentor: Dr. Herbert Meyer, Florissant Fossil Beds NM

Abstract

This paleoelevation study relies on hydrogen isotope ratios of meteoric water (precipitation) trapped in volcanic glass samples of latest Eocene to earliest Oligocene age from Wyoming, Colorado, New Mexico, and Texas. The goal of this research is to make an isotopic map in order to investigate the paleotopography of the Rocky Mountain region and uplift in the West.

Introduction

Estimates of paleoelevation have become a topic of interest to scientists. Mountains have a big effect on climate patterns due to their influence on precipitation and control on ecosystems. Models of paleoaltitudes can also help to determine timing of uplift events in geologic history.

Three main approaches have been used to model paleoaltimetry:

- Leaf physiognomy (shape) method: Uses either the differences of mean annual temperature or enthalpy at both sea level and the elevated area of study, assuming that characteristics of paleofloras and their correlation to climate is the same as modern floras.
- Vesicular basalt (extrusive volcanic rock with gas bubbles) method: Analyzed based on a correlation of paleoatmospheric pressure and the size distribution of vesicles; however, the eruption of basalt would occur at the volcano's height, above the mean elevation.
- Stable isotope method: Uses measurement of stable isotopes in fossil fish and mammal teeth, certain clays, volcanic ash, or lacustrine and soil carbonates. These materials preserve the record of isotope fractionation of hydrogen and oxygen of atmospheric water with elevation gain due to the thermodynamics of these elements as precipitation.

Methods

Stable isotope paleoaltimetry relates changes in the ratio between deuterium (heavy hydrogen, mass of 2) and hydrogen atoms in geologic materials to changes in this ratio in precipitation falling along an orographic barrier. Altitude and isotopic signature of precipitation are related because of Rayleigh distillation. Specifically, as air masses pass over mountains, precipitation at elevation is more depleted in deuterium than low-elevation precipitation. As a cloud ascends a mountain, the water adiabatically expands, cools, condenses, and the precipitation that follows removes heavy deuterium and oxygen isotopes.

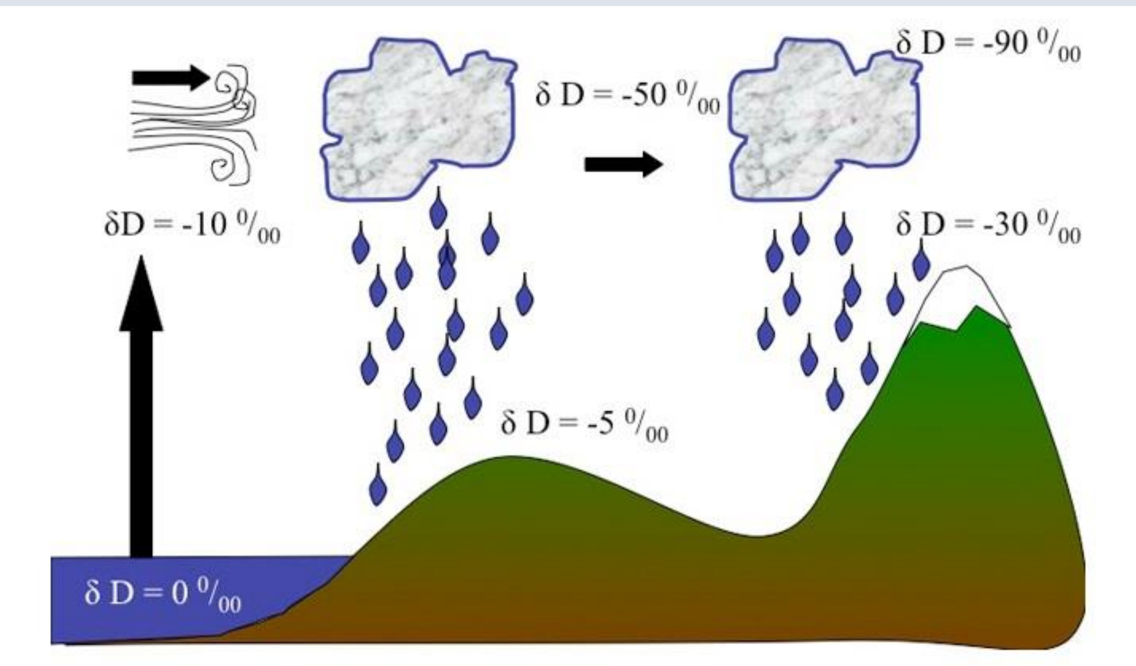
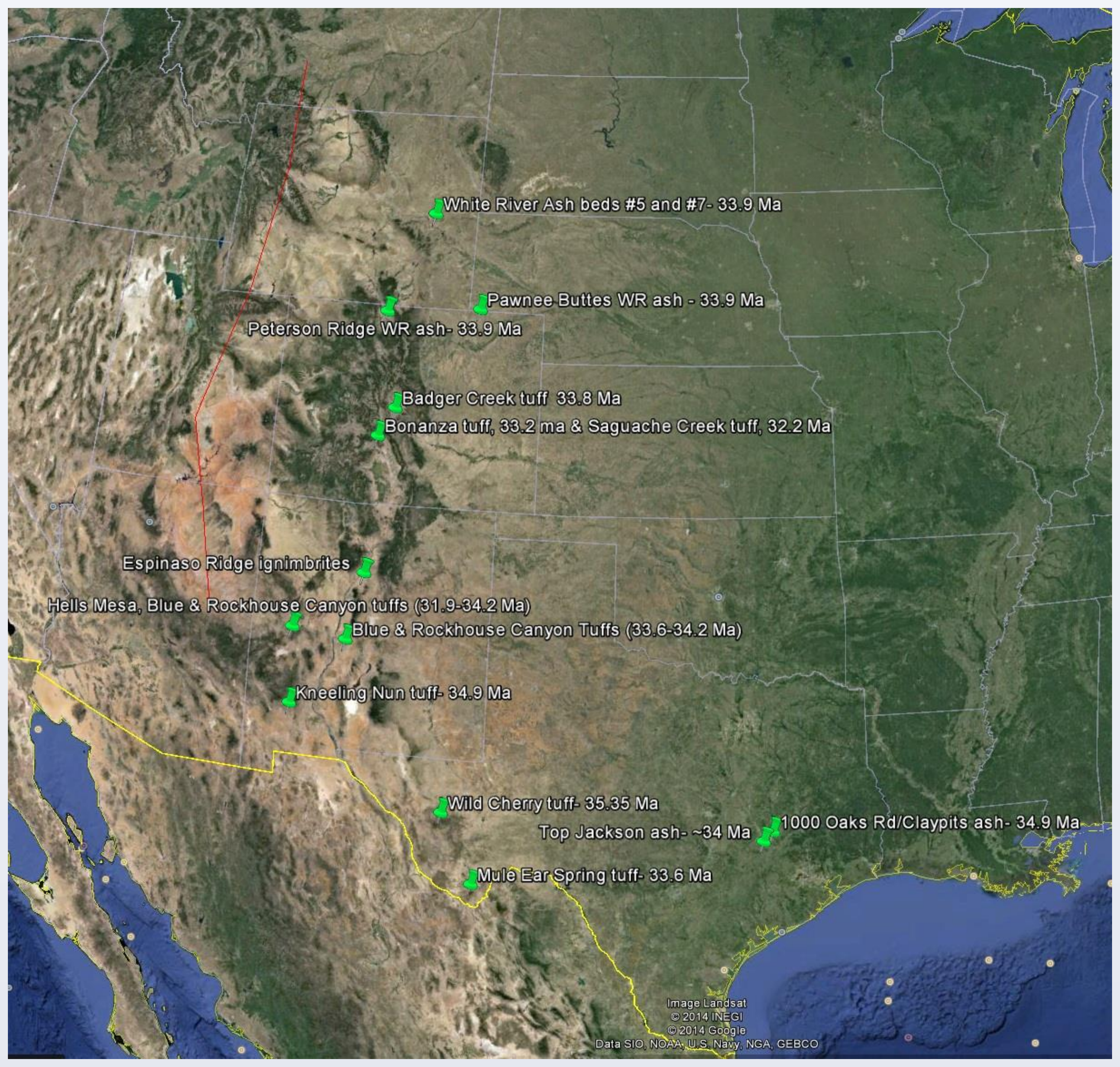


Illustration of hydrogen fractionation as precipitation is moved orographically as a result of the large relative mass difference between hydrogen and deuterium. Image credit: Jeff Kelly, University of Oklahoma

Volcanic glass is formed as a viscous magma cools rapidly. Environmental water diffuses into the glass within a few thousand years of deposition until it is completely saturated (length of time depending on the thickness of the walls of the glass), after which the water is very strongly bonded into the glass structure and will not be secondarily altered by further exchange of isotopes with the environment. This makes volcanic glass plausible for stable isotope paleoaltimetry study and a useful indicator of levels of hydrogen fractionation in paleoprecipitation.

Samples of tuff will be brought to the University of Idaho to be prepared and analyzed under the guidance of Dr. Elizabeth Cassel, who has performed a published isotopic study of similar nature. Rock samples will be crushed and sieved. Volcanic glass will be separated using SEM (scanning electron microscope), treated with HF (hydrofluoric acid), and washed to remove any clay alteration before analysis. Heavy liquid separations and isotopic analysis using a mass spectrometer will be performed.

Area of Study



Map showing sample localities with name of rock unit and age in millions of years (green pins) and estimated paleo continental divide during Eocene/Oligocene time (red line, left). Image credit: Google Earth

Late Eocene to early Oligocene pyroclastic rocks were deposited throughout the West as part of the mid-Tertiary ignimbrite flare up. This is largely attributed to the shallow subduction of the Farallon plate. Volcanic tuffs are the best candidates for this research because they are likely to contain glass due to the nature of rhyolitic ash-flow eruptions. Samples of volcanic material for the study are chosen based on their age and location along a backwards J-shaped transect (see map, above) that will include areas that are expected to have experienced uplift. Ages are based on Ar-Ar radiometric dating (where available, otherwise K-Ar or other methods) done in previous research, and all samples are within a confined age range of 35.35 and 33.2 million years old.

Field Work

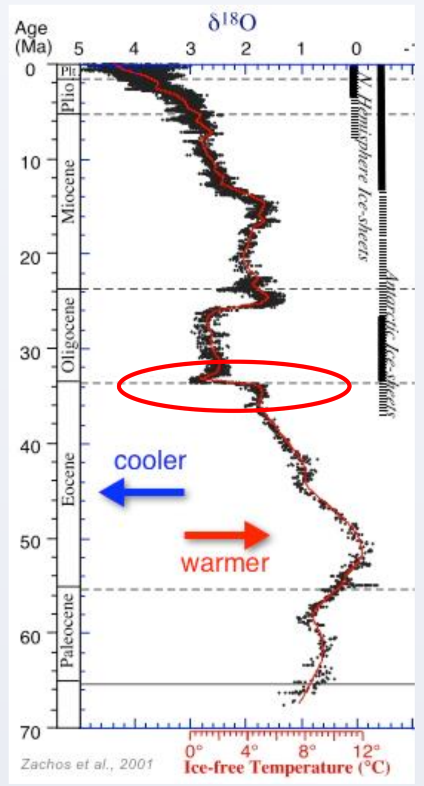
Collection of samples is currently in progress. The isotopic analysis requires a fist sized rock sample of each individual unit described in the map above. During my internship I have been able to collect six different samples in Colorado and Wyoming for my project. Through my Mosaics mentor, I have been in consultation with various researchers and had the guidance of Dr. Emmett Evanoff and Dr. Kent Sundell to identify sample localities geographically.

Top left: Identifying a Badger Creek Tuff outcrop for collection in South Park, CO with Dr. Herb Meyer and Dr. Libby Prueher; Top right: Examining Bonanza Tuff outcrop with Dr. Meyer in Saguache, CO; Bottom left: White River Ash 7, Douglas, WY; Bottom right: Overlooking the badlands in Douglas, WY with Dr. Kent Sundell pointing out white ash layers of the White River formation.

Significance of Research

While studies have been done west-east in the Rocky Mountains, no research has been done extending the transect to the south, where ignimbrites are also prevalent during the Middle Cenozoic. This research can fill the geographic gap in the hydrogen isotope data of the Western United States during the late Paleogene in order to better understand Cenozoic uplift on a continental scale.

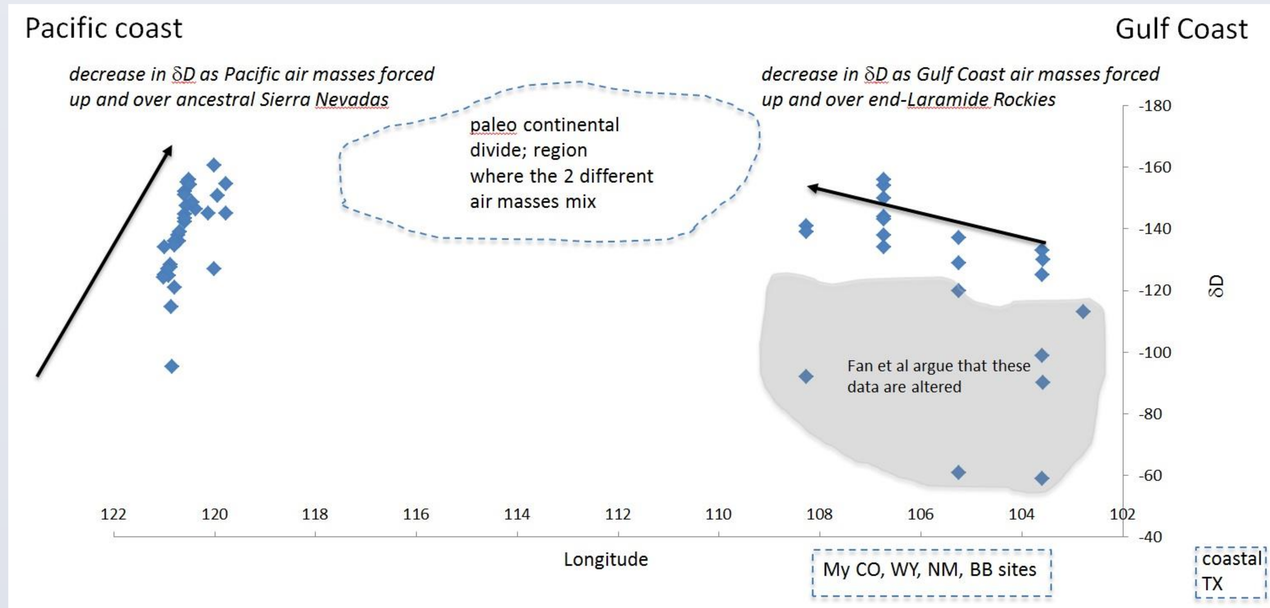
Further, the fact that these samples are all very similar in age gives the study better precision with respect to time than any other similar research done. These tuffs are also significant because they span the period in geologic time when Antarctic ice sheets were first permanently emplaced and began to significantly alter global climate, represented by the Zachos curve (right).



Curve showing the shift to cooler climate at the Eocene/Oligocene boundary.

Study Direction

Initial hydrogen isotope data for the study comes from previous research in the northern Sierra Nevada (Cassel et al. 2009) and Rocky Mountain/Great Plains region (Fan et al. 2014). These data will be included in our map and as part of our regional analysis.



Graph showing hydrogen isotope data from studies of the ancestral Sierra Nevadas and end-Laramide Rockies with longitude on the x-axis and deuterium on the y-axis. Below, dashed boxes show range in longitude of my samples, representing future data that will be added to the graph post-isotopic analysis.

Preliminary questions:

- Will data from my sites in the Rocky Mountains be same/different as those Fan et al. sampled at the same longitude? (Did they have similar elevations?)
- Will the coastal Texas sites have data much different than the inland sites? (Was there a significant elevation difference between them?)

Timeline of Project, 2014-2015

June- Research and Project Planning
July- Collection of samples in CO, WY
Late August- Collection of samples in NM
Late October- Collection of samples in TX
November- Sample analysis/lab work at University of Idaho
Late January- Draft of first sections of research paper due to CC Geology Dept.
March- Draft of entire Research paper due
April- Presentation at CC Geology Day
May- Final Research paper due, presentation at GSA Rocky Mountain Section meeting in WY

References

Concepts for this study are derived from the following sources:

Cassel, E.J., Graham, S.A., and Chamberlain, C.P., 2009, Cenozoic tectonic and topographic evolution of the northern Sierra Nevada, California, through stable isotope paleoaltimetry in volcanic glass: Geology, v. 37, p. 547-550.

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